7.0 PLANT INSTRUMENTATION AND CONTROL

7.1 PROTECTIVE SYSTEMS

7.1.1 DESIGN BASIS

The reactor protection system receives, from plant instrumentation, signals which are indicative of an approach to an unsafe operating condition, actuates alarms, prevents control rod motion, initiates load cutback, and/or opens the reactor trip breakers, depending on the severity of the condition.

7.1.2 SYSTEM DESIGN

A simplified block diagram of the Reactor Protection System is shown in Figure 7-1. Individual reactor trip signals provided by the Reactor Protection System are:

a) Manual reactor trip:

Manual buttons are positioned for immediate use by plant operators when needed.

b) High startup rate:

These circuits are tripped when the rate of nuclear power increase exceeds a set point during operation in the intermediate range of the Nuclear Instrumentation System.

c) High nuclear flux:

The trip set points for these circuits will be set at a relatively low level during startup and set above full power during operation.

d) Safety injection:

Actuation of the Safety Injection System will initiate reactor trip signals.

e) Variable low pressure:

A reactor trip will result if the pressurizer pressure falls below a variable set point. The purpose of these circuits is to prevent reactor coolant conditions in the core which might lead to excessive fuel or cladding temperatures or to excessive bulk boiling. The set point for this reactor trip is calculated from temperature detectors in the reactor coolant piping and automatically adjusted.

x

f) Fixed high pressure:

High pressurizer pressure will initiate a reactor trip. The purpose of these circuits is to protect the Reactor Coolant System against over-pressurization and to limit the range in which protection by the variable low pressure reactor trip circuits is required.

g) Loss of coolant flow:

A signal of low coolant flow in any loop when operating above a pre-set power level will cause a reactor trip. Loss of reactor coolant pump power provides a similar initiation signal for this reactor trip.

h) Turbine-generator trip:

Trip of the turbine-generator initiates a reactor trip to prevent ex-cessive reactor coolant temperature and/or pressure.

i) Loss of feedwater supply:

This signal prevents excessive reduction in water inventory in steam generators.

Reactor trip signals are interlocked with measurements of nuclear power and steam power to allow the necessary system operations and control rod movements during startup and to remove the startup rate reactor trip when the reactor is in the power range of operation.

Wherever feasible, elements of reactor trip channels will be designed to trip the channel for the most probable failure. Except where an adequate backup exists, redundant channels will be used such that no single failure of any element can prevent or cause a reactor trip.

All reactor trip signals will trip both reactor trip breakers through inde-pendent wiring. Also, a third independent reactor trip wiring circuit will be provided to trip the undervoltage coils on both breakers.

Automatic turbine load cutback is initiated by a signal of a dropped control rod cluster as indicated by either a rapid decrease in nuclear flux or by the rod bottom on-off controllers. This will prevent high power operation which might lead to unsafe core conditions because of the asymmetric nuclear flux distribu-tion resulting from a dropped rod cluster. Automatic control rod withdrawal is also blocked for this condition.

Conditions which will block control rod withdrawal are listed below:

a) Rod drop (explained above)

b) High startup rate. This rod stop will block both manual and automatic control rod withdrawal. The set point for this rod stop will be less than that for the high startup rate reactor trip.

c) High nuclear flux. This rod stop will also block both manual and automatic rod withdrawal, and will be actuated at a lower value than the high nuclear flux reactor trip set point.

A shutdown margin alarm circuit computes the lower limit to which the control group can be moved and still retain the required shutdown margin of reactivity of at least one per cent. Reactor coolant temperatures and control group position are used for this computation.

Alarms will also be used to alert the operator to deviation from normal operating conditions so that, where possible, he may take corrective action to avoid a reactor trip. Further, actuation of any rod stop or trip of any reactor trip channel will actuate an alarm.

7.2 REGULATING SYSTEMS

7.2.1 DESIGN BASES

Overall reactivity control is achieved by the combination of chemical shim and control rod clusters. Long-term regulation of core reactivity is accomplished by adjusting the concentration of boric acid in the reactor coolant. Short-term reactivity control for power changes or reactor trip is provided by movement of control rod clusters. A simplified block diagram of the Reactor Control System is shown in Figure 7-2.

The primary function of the Reactor Control System is to provide automatic control of the rod clusters during power operation of the reactor. The system uses input signals including neutron flux; coolant temperature and pressure; control rod position; and plant turbine load. The Chemical and Volume Control System serves as a secondary reactor control system by addition and removal of varying amounts of boric acid solution.

The Reactor Control System will be designed to enable the reactor to follow load changes automatically when the plant output is above 15% of nominal power. Control rod positioning may be performed automatically or manually by the operator, when plant output is above this value.

The system enables the nuclear plant to accept generation step load increases of 10% and ramp increases of 5% per minute within the load range of 15% to 100% without reactor trip subject to possible xenon limitations late in core life. Similar step and ramp load reductions are possible within the range of 100% to 15% of nominal power. Based on experience, however, greater capabilities are to be expected as the operating conditions will probably not be as pessimistic as those used design conditions.

7.2.2 SYSTEM DESIGN

7.2.2.1 Reactor Coolant Temperature Control

The primary function of the Reactor Coolant Temperature Control System is to maintain a programmed average reactor coolant temperature during steady-state operation which rises in proportion to load. The control system also limits reactor plant system transients for prescribed load perturbations to within prescribed limits about this programmed temperature.

The measurements of the average temperatures are made by pairs of resistance thermometers in each of the reactor coolant loops. Elements in each cold leg in series with elements in the associated hot legs are used to produce outputs proportional to the average temperature. The controller compares the average loop temperature with the programmed temperature, which is set by a signal proportional to turbine-generator load.

The controller acts to direct a group of control rod clusters, fixed in number and location (the "control group"), to increase or decrease reactor power as required to maintain the desired average temperature. This group of rods is sequentially actuated with a proportional speed control (see Rod Drive Programmer). The sequential mode of operation provides fine temperature control for steady-state operation and long-term reactivity effects such as core burnup by limiting the stepwise reactivity insertion to that associated with a small number of rod clusters. For rapid reactivity changes to accomodate relatively large changes in load, the control group is driven at a higher rate through the proportional speed control so that the rods in the control group move in rapid sequence.

Large and rapid changes in load are accompanied by relatively large reactor coolant pressure changes. A pressure signal and a nuclear power signal are used in addition to the average temperature signal to improve the control response.

7.2.2.2 Steam Dump Control

A modulating steam dump control system is provided to remove sensible heat stored in the Reactor Coolant System following a plant trip. With the programmed average temperature, the full load average temperature is significantly greater than the saturation temperature corresponding to the steam generator safety valve set pressure. This, together with the fact that the thermal capacity in the Reactor Coolant System is greater than that of the steam system, requires a heat sink to prevent actuation of the steam generator safety valves following a plant trip. The total dump capacity to the condenser is 40 per cent of the steam flow corresponding to plant operation at 100% power.

7.2.2.3 Control of Shutdown Groups

The shutdown groups of control rods together with the control group are capable of shutting the reactor down. They are used in conjunction with the adjustment of chemical shim and the control group to maintain an adequate shutdown margin of at least one per cent for all normal operating conditions. These shutdown groups are manually controlled, except for automatic trip signals and are moved at a constant speed. They are fully withdrawn during power operation and are withdrawn first during startup. Criticality is always approached with the control group after withdrawal of the shutdown groups.

7.2.2.4 Interlocks

The control group used for automatic control is interlocked with measurements of turbine-generator load and reactor power to prevent automatic control rod withdrawal below 15% of nominal power. The manual and automatic controls are further interlocked with measurements of startup rate, nuclear flux, reactor coolant pressure and temperature, and rod drop indication to prevent approach to an overpower condition.

7.2.2.5 Rod Drive Programmer

The control group is driven by a sequencing, variable speed rod drive programmer. In the control group of RCC assemblies, control subgroups (each containing a small number of RCC assemblies) are moved sequentially in a cycle such that all subgroups are maintained within one step of each other.

The sequence of motion is reversible, that is, a withdrawal sequence is the reverse of the insertion sequence. The sequencing speed is proportional to the control signal from the reactor control system. This provides control group speed proportional to the demand signal from the control system.

A rod drive mechanism control center is provided to receive sequenced signals from the programmer and to actuate contactors in series with the coils of the rod drive mechanisms. Two reactor trip breakers are placed in series with the supply for these coils.

7.2.2.6 Control Rod Cluster Position Indication

Two methods of indicating control position are provided. The first method of indicating positions of control rod shutdown groups and control group rod subgroups is by counting the number of steps that the rods in a group have been moved by the magnetic jacks. This is accomplished by pulse transmitting contacts associated with the cylcing mechanisms of the programmer and magnetic jack contactors feeding a digital readout device. For each step by a group of rod clusters, the digital readout receives an impulse and adds to or subtracts from the previously indicated position.

A second method of rod position detection for the individual rods is provided by position transmitters which are electrical coil stacks placed above the stepping mechanisms of the control rod magnetic jacks external to the pressure housing. When the associated control rod is at the bottom of the core, the magnetic coupling between a primary and secondary is small and there is a small voltage induced in the secondary. As the control rod is raised by the magnetic jacks, the relatively high permeability of the lift rod causes an increase in magnetic coupling. Thus an analog signal proportional to rod position is derived. Rod bottom lights are provided to indicate the approximate fully inserted rod position. In addition a multipoint recorder is provided to record position of the rods in selected groups as determined by the operator for particular operating conditions.

7.2.2.7 Rod Drive Power Supply

The dc power for the entire complement of rod drive mechanisms is provided by two ac motor generator sets and static rectifier assemblies. The motor generator sets will consist of squirrel cage induction motors driving synchronous alternators.

The total capacity of the system including the overload capability of each motor generator set is such that a single set out of service will not cause limitations in rod motion during normal plant operation. In order to prevent reactor trip as a result of a unit malfunction, the power system will normally be operated with both units in service.

Flywheels on the motor generator sets and high speed regulators on each unit will enable the rods to ride through a complete loss of ac power for one second during electrical transients.

7.3 NUCLEAR INSTRUMENTATION SYSTEM

7.3.1 DESIGN BASIS

The function of the Nuclear Instrumentation System shown on Figure 7-3 is to monitor the reactor power from source range through the intermediate ranges and up to 120 per cent of full power. This is accomplished by means of thermal neutron flux detectors located in instrument wells in the primary shield area adjacent to the reactor vessel. The system provides indication, control and alarm signals for reactor operation and protection. The overlap of the ranges of detection is indicated on Figure 7-4.

7.3.2 SYSTEM DESIGN

7.3.2.1 Detectors

The system employs six detector assemblies located in instrument wells around the reactor. Two of these detectors are proportional counters used in the source range channels. They are located in vertical instrument wells adjacent to two opposite "flat" portions of the core at an elevation equal to the axial center of the core.

The other four detector assemblies are long ionization chambers approximately equal to the core height. The inner electrodes are divided into two equal sections to supply in effect a total of eight separate ionization chambers approximately one-half the core height. The bottom halves of two of the chambers and the top halves of the other two also contain gamma compensation volumes for combined use in the intermediate and power range channels, and for reactivity or other physics measurements. The four long ionization chamber assemblies are located in vertical instrument wells adjacent to the four "corners" of the core.

7.3.2.2 Source Range

There are two source range channels utilizing proportional (BF_3) counters. Neutron flux, as measured in the primary shield area, produces current pulses in the detectors. These pulses are applied to transistor amplifiers and discriminators located in the control room.

These channels indicate the source range neutron flux, startup rate, and the BF_3 high voltage, and provide startup rate rod stop and alarm signals to the Reactor Control and Protection System. An audible count rate signal is used during initial phases of startup in both the vapor containment and the control room.

7.3.2.3 Intermediate Range

There are two intermediate range channels, which utilize two of the compensated sections of the long ionization chambers. Direct current from the ion chambers is transmitted through cables to transistor current and rate amplifiers in the control room, and is also utilized in two of the power range amplifiers.

These channels indicate the intermediate neutron flux and startup rate, and provide startup rate rod stop and alarm signals and startup rate reactor trip signals. They also automatically disconnect the high voltage from the source range detectors when the flux level is in the intermediate range.

7.3.2.4 Power Range

There are three sets of power range measurements, each utilizing four individual currents as follows:

a) Four currents directly from the lower sections of the long ionization chambers.

b) Four currents directly from the upper sections.

c) Four total currents of (a) and (b), equivalent to the average of each section.

For each of the four currents in (a) and (b), the current measurement is indicated directly by a microammeter. The total current equivalent to the average is then applied to an amplifier and bistable trip circuit with indication by meter-relays. The amplifiers are equipped with gain and bias controls for adjustment to the actual dc current corresponding to the equivalent per cent of reactor thermal power.

Each of the four amplifiers also provides amplified currents to the main control board for indiciation and for use in the Reactor Control System. Each set of bistable trip outputs is operated in 2-out-of-4 coincidence to initiate a reactor trip. Bistable trip outputs are provided at different power set points depending on the operating power to provide protection against excessive errors resulting from large control rod movements.

The meter relay, reading the amplifier current in each channel, will provide as a minimum a low and high level signal (low level might be indication of a failed channel and initiate an alarm - high level might be indication of an approach to overpower condition and initiate a rod stop).

The four amplifier signals for (c) are supplied to circuits which compare each individual chamber current with the corresponding current in all other detectors. Alarms are provided to present deviations which might be indicative of quadrant flux asymmetry.

7.3.2.5 Auxiliary Equipment

A conventional micro-microammeter is connected to any one of the intermediate or power range detectors. This is for use in physics tests.

A large two-pen strip chart recorder is mounted on the main control board for use by the plant operators. It includes a range switch for following the power rise of the reactor in steps of two decades or complete coverage by logarithmic charts of the source and the intermediate ranges. It also records neutron flux during power range operation.

7.3.2.6 Overpower Trip Set Point

The overpower trip set point for the Indian Point Unit No. 2 Reactor is 106.5%. This trip point was selected to provide adequate assurance that spurious reactor trips will not occur in normal operation. This set point, which is lower than that previously employed (111% in Connecticut Yankee and SCE), is made possible by the use of long ion chambers and improved solid state electronic devices in the instrumentation system. Table 7-1 gives a comparison of the factors which determine the trip set point for the Indian Point Unit No. 2 reactor and those used in other designs.

TABLE 7-1
OVERPOWER TRIP SET POINT

Set Point Factor	Indian Point Unit No. 2 (percent)	Previous Designs (percent)
Normal Power	100.0	100.0
Overshoot	3.0	3.0
Errors in Ion Chamber Output Due to RCC Motion for Design Transients	1.5	4.0
Errors Due to Drift and Set Point Reproducibility	2.0	4.0
Set Point	106.5	111.0

As shown by the information in Table 7-1, the difference in set point is due to reduction in errors due to RCC motion from +4% to ±1.5% and a reduction in drift and set point errors from ±4% to ±2%.

The reduction in errors due to RCC motion is made possible by the use of long ion chambers instead of short ion chambers at the top and bottom of the core. These long ion chambers, which extend over almost the entire core length, give a more accurate indication of flux changes than the combination of detectors at the top and bottom of the core. Tests at CVTR have demonstrated the performance of the long ion chambers and during initial start-up tests the performance of these detectors as installed in Indian Point will be verified.

The reduction of drift and set point errors is due to the use of the more accurate, solid state electronic devices. The performance of these devices has been demonstrated in Saxton. Application of the reduced trip set point and improved performance of these control devices results in a maximum calculated overpower of 112% as compared with 118% obtained with previous designs. Table 7-2 gives a comparison of factors to which this difference is attributed.

TABLE 7-2
MAXIMUM OVERPOWER LEVEL

Overpower Factor	Indian Point Unit No. 2 (percent)	Previous Designs (percent)
Normal Power	100.0	100.0
Calorimetric Error	2.0	3.0
Overshoot	3.0	3.0
Errors in Ion Chamber Output Due to RCC Motion for Design Transient	3.0	4.0
Errors Due to Drift and Set Point Reproducibility	4.0	8.0
Maximum Overpower	112.0	118.0

It is seen that the reduction in overpower is due to (1) a reduction from 3.0 to 2.0 in the allowed calorimetric error, based on experience with conventional stations, and (2) the effects of reduced errors due to rod motion, drift, and set point reproducibility as described earlier. The net result is an improvement in plant capability with the same assurance against both spurious trips and excessive power as was afforded by previous designs.

7.4 NON-NUCLEAR PROCESS INSTRUMENTATION

Much of the process instrumentation provided in the plant has been described in the Reactor Control and Protection System and Nuclear Instrumentation System. The more important instrumentation used to monitor and control the plant has been covered in detail in the above systems. The remaining portion of the process instrumentation is generally shown on the process flow diagrams which have been included to illustrate the operations and processes of the various auxiliary systems and the turbine-generator plant.

This remaining portion of the process instrumentation is generally detailed on the individual systems flow diagrams. The amounts and types of the various instruments and controllers shown are intended to be typical examples of those which will be included in the various systems when final design details have been completed.

7.5 IN-CORE INSTRUMENTATION

7.5.1 DESIGN BASIS

The in-core instrumentation is designed to yield information on the neutron flux distribution and fuel assembly outlet temperatures at selected core locations. Using the information obtained from the in-core instrumentation system, it will be possible to confirm the reactor core design parameters and calculated hot channel factors.

7.5.2 SYSTEM DESIGN

The in-core instrumentation system consists of thermocouples positioned to measure fuel assembly coolant outlet temperature at preselected locations and flux thimbles which run the length of selected fuel assemblies to measure the neutron flux distribution within the reactor core. The exact number and locations will be set following final selection of the control rod pattern. Preliminary evaluations indicate that 65 thermocouples and 56 flux thimbles will be used.

The experimental data obtained from the in-core temperature and flux distribution instrumentation system in conjunction with previously determined analytical information, can be used to determine the fission power distribution in the core at any time throughout core life. This method is more accurate than using calculational techniques alone. Once the fission power distribution has been established, the maximum power output is primarily determined by thermal and hydraulic conditions existing within the core. A combination of the fission power distribution and the thermal and hydraulic limitations determines the maximum core capability.

The in-core instrumentation provides information which may be used to calculate the coolant enthalpy distribution, the fuel burnup distribution, and an estimate of the coolant flow distribution.

7.5.2.1 Thermocouples

Sixty-five chromel-alumel thermocouples are threaded into guide tubes that penetrate the reactor vessel head through seal assemblies, and terminate at the exit flow end of the fuel assemblies. The thermocouples are enclosed in stainless steel sheaths within the above tubes to allow replacement if necessary. Thermocouple readings are recorded continuously on multipoint recorders located in the control room. The support of the thermocouple guide tubes in the upper core support assembly is described in Section 3.2.3.

7.5.2.2 Movable Miniature Neutron Flux Detectors

Six detectors will be remotely positioned in the core and will provide remote readout for flux mapping. The basic system for the insertion of these six miniature detectors will be as shown in Figures 7-5 and 7-6. Fifty-six retractable thimbles into which the miniature detectors will be driven are pushed into the reactor core through conduits which extend from the bottom of the reactor vessel down through the concrete shield area and then up to a thimble seal line. The minimum bend radius will be 90 inches.

The thimbles will be closed at the leading ends, will normally be dry inside, and will serve as the pressure barrier between the reactor water pressure and the atmosphere. Mechanical seals between the retractable thimbles and the conduits will be provided at the seal line.

During normal operation, the retractable thimbles will be stationary. They will be extracted upward approximately 15 ft. for maintenance or during refueling, at which time a space of approximately 15 ft. above the seal line must be cleared for the retraction operation.

The retractable thimbles are extracted during refueling, to avoid interference within the core.

The drive system for the insertion of the miniature detectors will consist basically of six drive assemblies, six path-group selector assemblies and six rotary selector assemblies, as shown in Figure 7-6. The drive system will push hollow helical-wrap drive wires into the core with the miniature detectors attached to the leading ends of the wires and small diameters sheathed coaxial cables threaded through the hollow centers back to the trailing ends of the wires.

Each drive assembly mainly consists of: a gear motor that provides sufficient power to push a drive wire and detector through any path; a drive box with a drive wheel that couples with the helical-wrap drive wire and is driven by the gear motor (the top half of the drive wheel cover shall be readily removable in order to insert the drive wire by pushing the leading end with the detector attached downward into the flux thimble, and pushing the trailing end with an electrical seal attached back to the storage reel); and a storage device consisting of a takeup reel that accommodates the total drive wire length.

One path-group selector is provided for each drive unit to route the detector into one of the six groups of flux thimbles.

Each rotary transfer assembly mainly consists of: a rotary transfer device that routes a detector into any one of up to ten selectable paths; and up to ten isolation valves, manually operated to close the thimble runs after removal of the detector. Each of these valves, when open, shall allow free passage of the detector and drive wire and when closed shall prevent steam leakage from the core in case of a thimble rupture.

A path common to each group of flux thimbles is provided to permit a cross-calibration of the six detectors.

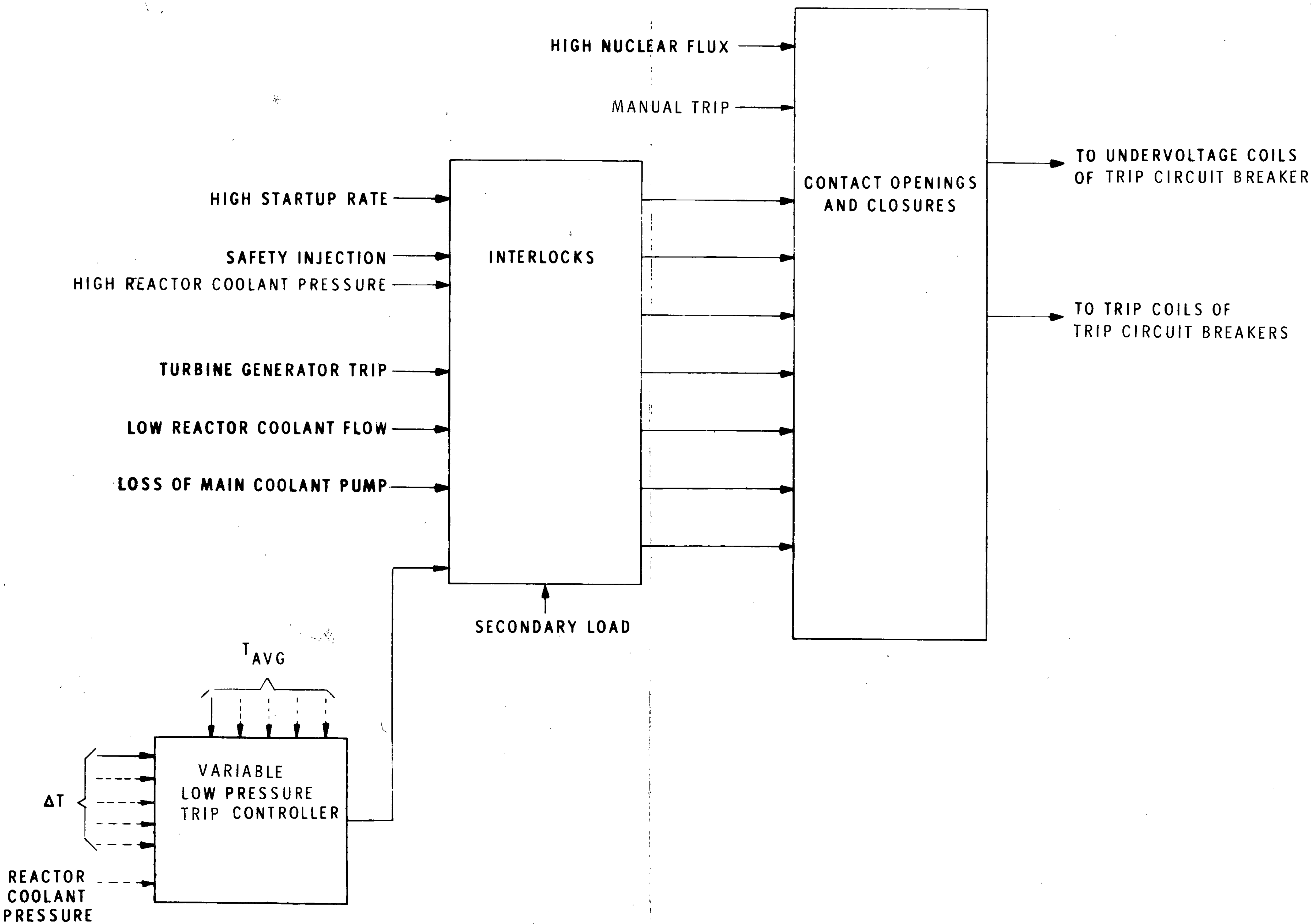
7.6 RADIOACTIVITY INSTRUMENTATION

The description and design basis for the Radioactivity Instrumentation are given in Section 11.2.

7.7 OPERATING CONTROL STATIONS

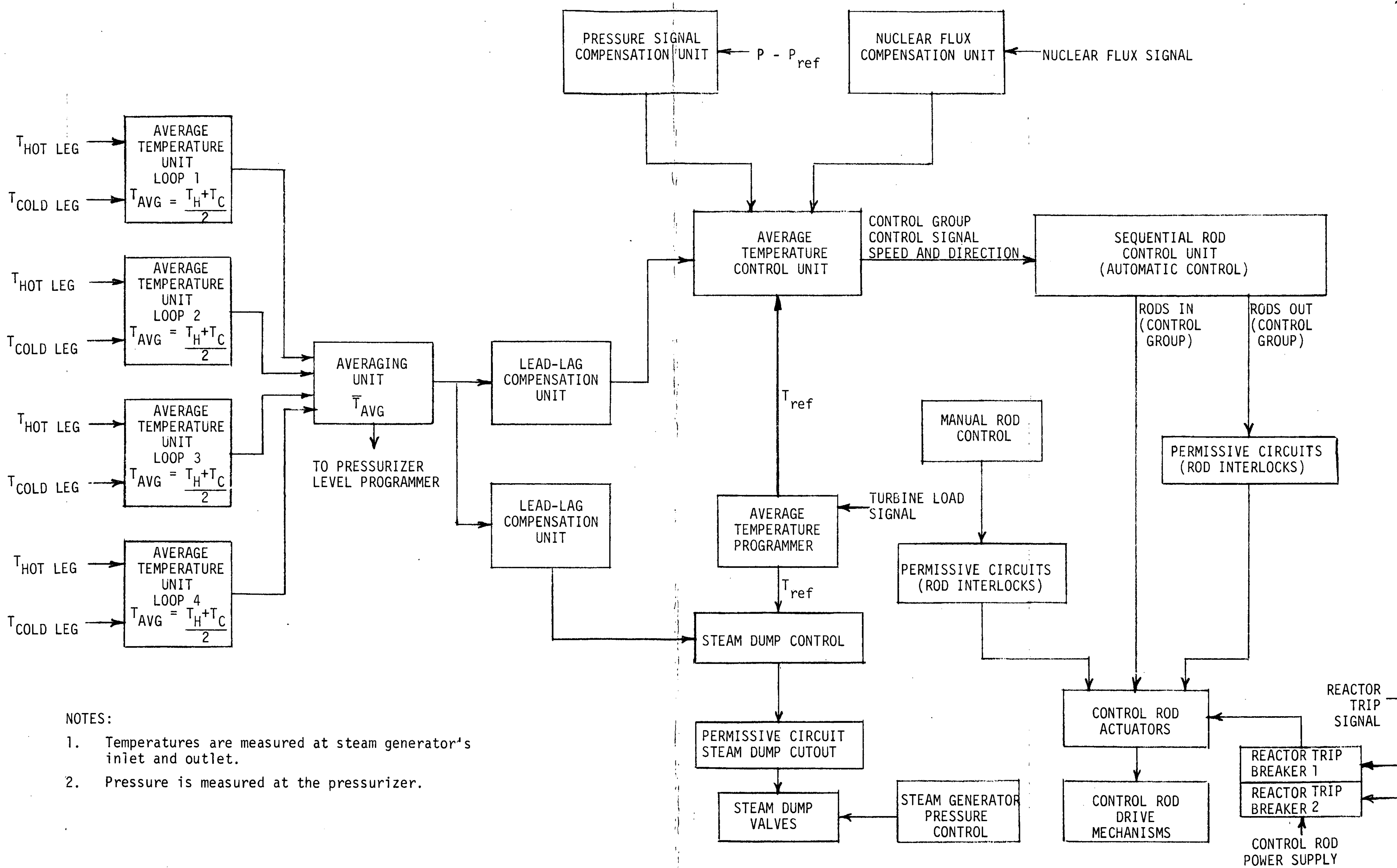
The principal criterion of control station design and layout is that all controls, instrumentation displays and alarms required for the safe operation and shutdown of the plant are readily available to the operators in the control room. Alarms and annunciators in the control room provide the operators warning of abnormal plant conditions which might lead to damage of components, fuel or other unsafe conditions. Other displays and recorders are provided for indication of routine plant operating conditions and for the maintenance of records.

Local control panels are provided for systems and components which do not require full time operator attendance or are not used on a continuous basis. Examples of such systems are the Waste Disposal System and the Turbine Generator Hydrogen Cooling System. In these cases however, appropriate alarms are located in the control room and are activated to alert the operators of equipment malfunction or approach to unsafe conditions.



ED SK 328305-C

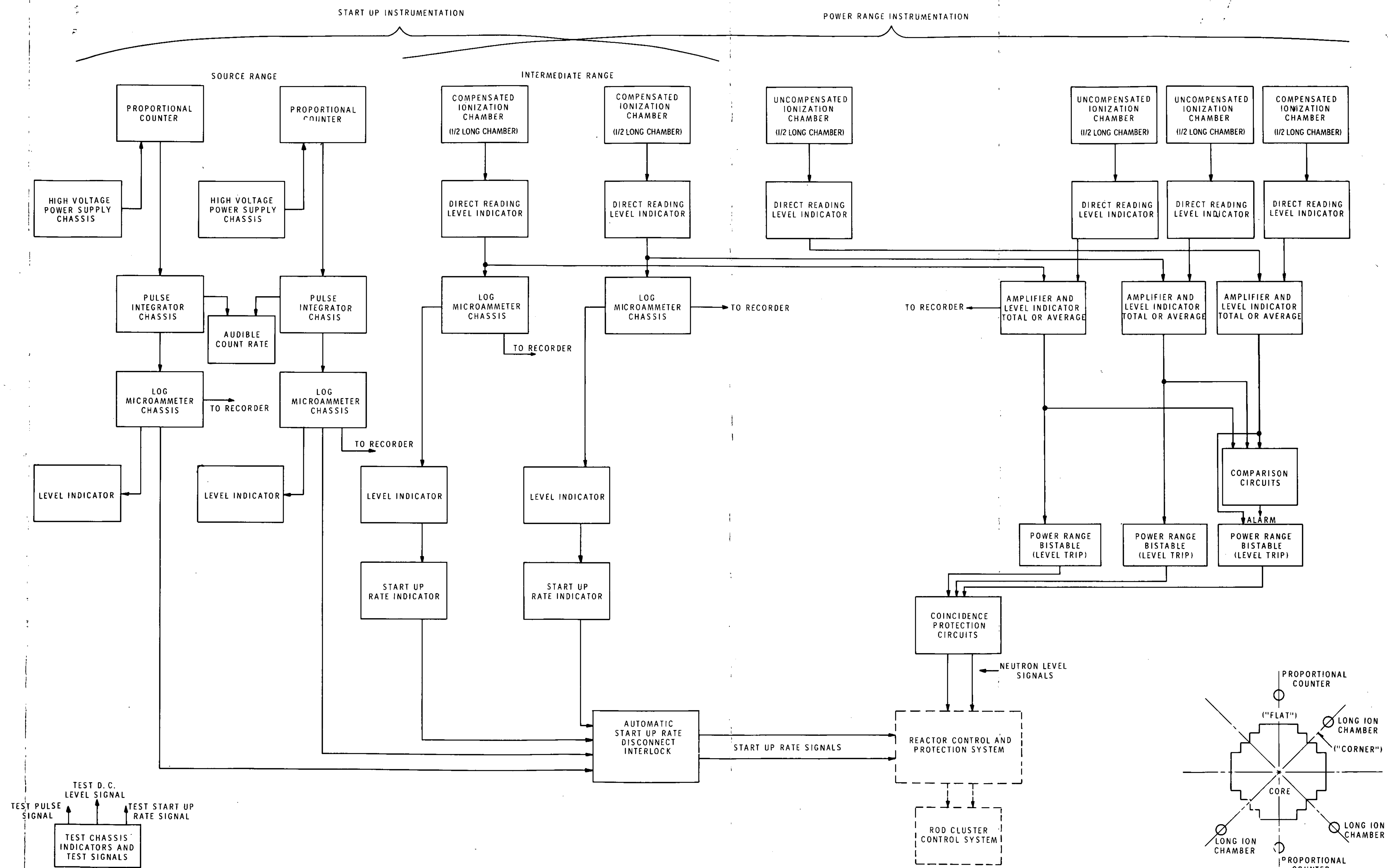
REACTOR PROTECTION SYSTEM
FIG. 7-1



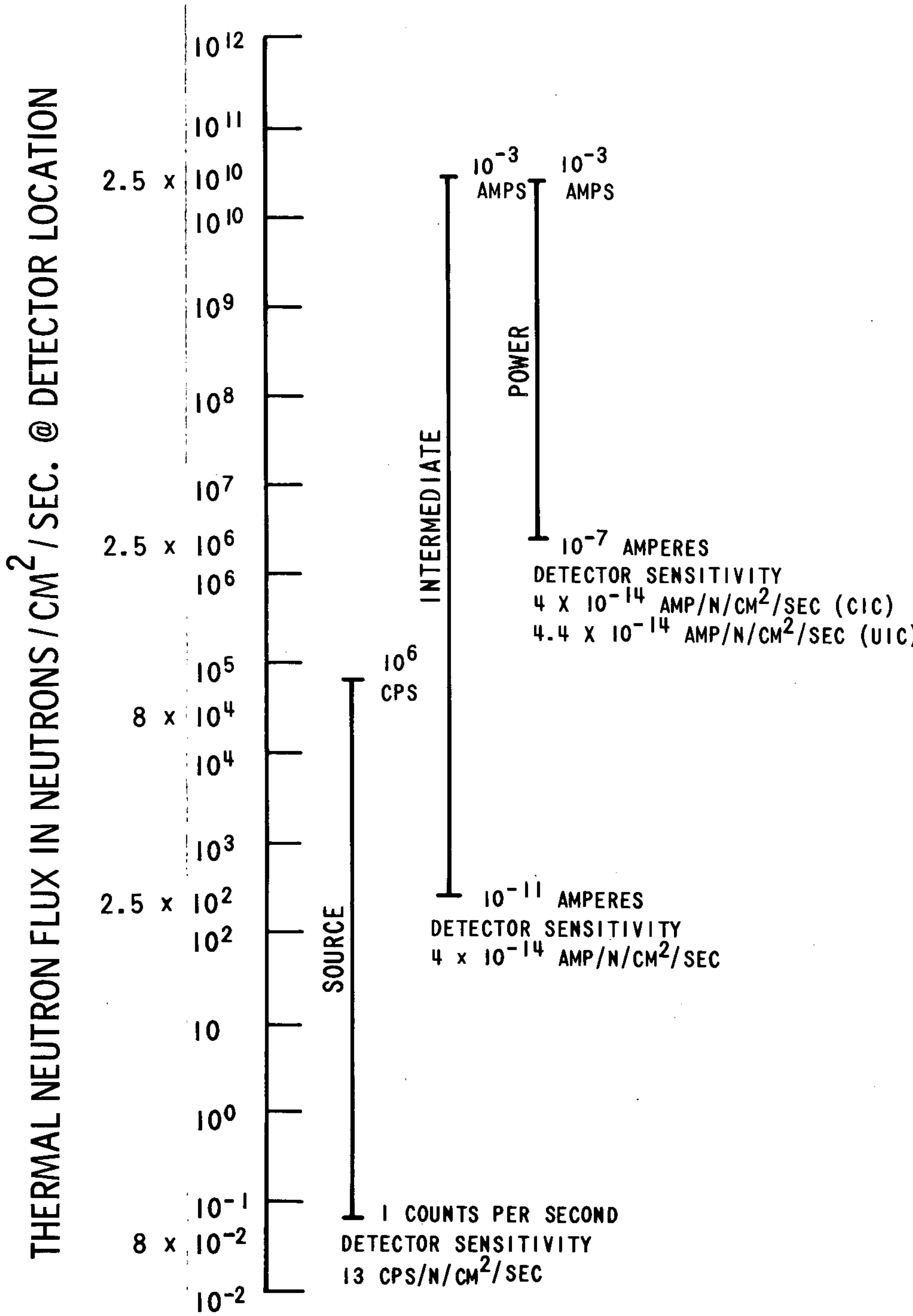
NOTES:

1. Temperatures are measured at steam generator's inlet and outlet.
2. Pressure is measured at the pressurizer.

SIMPLIFIED BLOCK DIAGRAM OF REACTOR CONTROL SYSTEMS
FIG. 7-2

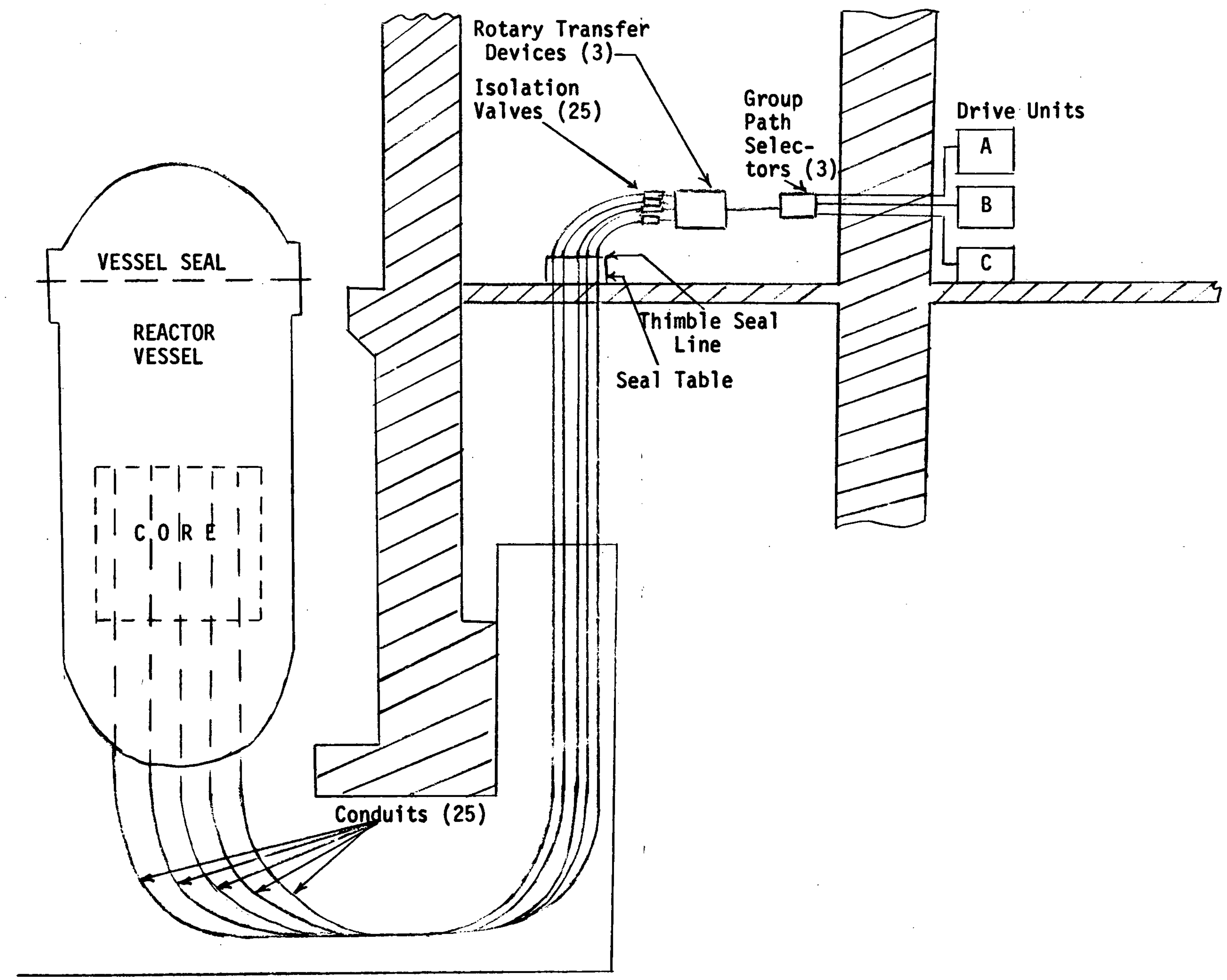


NUCLEAR INSTRUMENTATION SYSTEM
FIG. 7-3

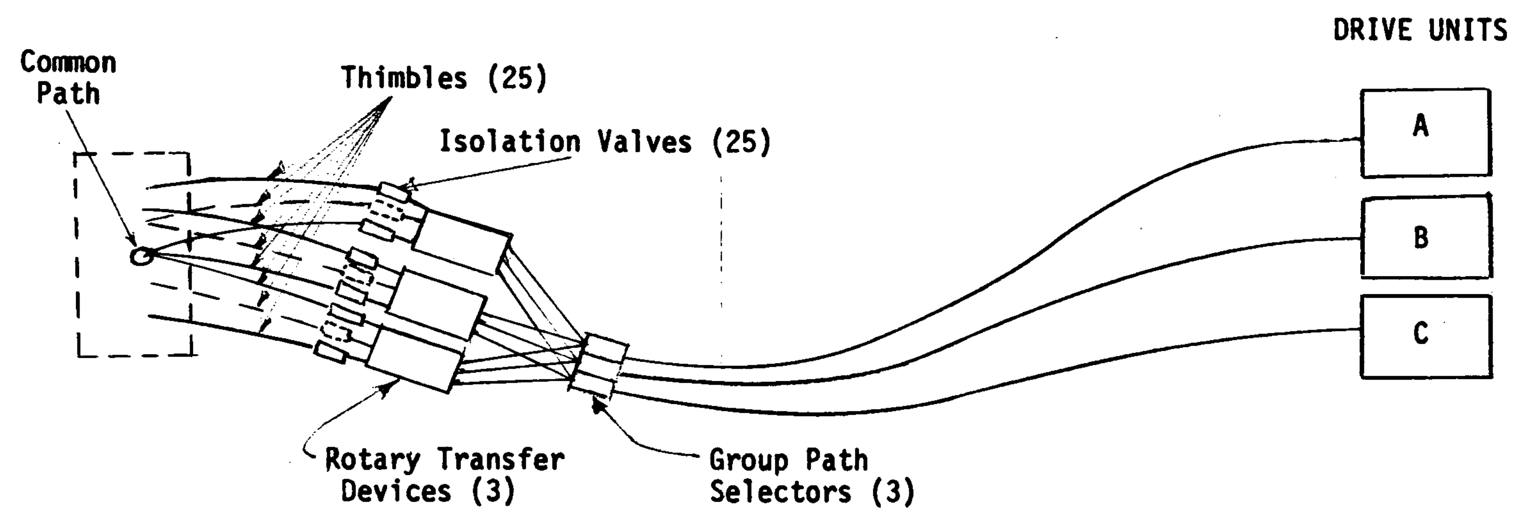


NEUTRON DETECTORS & RANGE OF OPERATION
NUCLEAR INSTRUMENTATION SYSTEM

SENSITIVITY OF THE REACTOR NEUTRON DETECTORS
FIG. 7-4



ARRANGEMENT OF MOVABLE MINIATURE NEUTRON FLUX DETECTOR SYSTEM
FIG. 7-5



SCHEMATIC OF MOVABLE MINIATURE NEUTRON FLUX DETECTOR SYSTEM
FIG. 7-6